

**The Highways Agency's  
Interim Climate Change Risk Assessment**  
December 2010



## Overview

The Climate Change Act (2008) gave government a range of powers to address climate change adaptation. In addition to the requirement for a National Adaptation Programme and UK Climate Change Risk Assessment, the Act also provides an Adaptation Reporting Power. This power is being used to direct companies to produce reports which consider their risks from climate change and require them to put together programmes of measures to deal with these risks.

The Climate Change Act 2008 defines reporting authorities as 'persons or bodies with functions of a public nature' and by implication excludes central Government Departments and Executive Agencies of those departments. However, the Highways Agency was highlighted as being at particular risk of climate change impacts. We have a key role to play in ensuring the UK's infrastructure is adapting to the impacts of a changing climate. We therefore volunteered to report expecting that this report will have a role in informing the National Adaptation Programme and UK Climate Change Risk Assessment.

Guidance has been issued by Defra and supplemented by a risk assessment framework developed by Cranfield University which will be used to evaluate submissions. This assessment draws heavily on the published [Highways Agency Climate Change Adaptation Strategy and Framework](#)<sup>1</sup> which is available to stakeholders for review on the intranet and internet.

### 1. Highways Agency functions impacted by climate change

The Highways Agency is an executive agency of the Department for Transport (DfT) and is responsible for operating, maintaining and improving the strategic road network in England on behalf of the Secretary of State for Transport. This network is a key component of the country's overall transportation infrastructure, linking with local roads and other transportation modes, carrying a third of all traffic in England, and two thirds of all heavy freight traffic.

The Highways Agency's network includes over 7500 km of roads ranging from motorways carrying up to 200,000 vehicles per day to single carriageway trunk roads carrying fewer than 10,000 vehicles per day. The network is valued at over £87 billion. It incorporates an extensive asset base including bridges, earthworks, tunnels, and the technology that supports the network's effective operation. As a result we must ensure that the network continues to function in the face of a changing climate.

We seek to ensure that the strategic road network operates safely, efficiently and effectively, and is capable of meeting the demands placed upon it in an increasingly sustainable manner:

- We focus on the performance of the network as a priority, maintaining and renewing ageing parts of the physical asset. Delivering reliable journeys is one of the Highways Agency's prime objectives. This role is central to the economic

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<sup>1</sup> <http://www.highways.gov.uk/aboutus/24180.aspx>

prosperity of the nation and is important to all road users. Whether travelling for leisure or business, road users rightly expect their journey time to be predictable.

- Our asset is vast and varied, including road pavements, footways, streetlights, cycle ways, earthworks, signs, drains, road markings, structures, verges and our national and regional control centres. Beyond the visible asset, we also have a large telecommunications network comprising cables, sensors and displays. Managing the asset effectively by improving and maintaining it in a safe and serviceable condition is vital. Britain's roads are among the safest in the world. Over the last five years the number of people who have been killed or seriously injured has fallen by 23%.
- Sustainability concerns the formulation of lasting economic, social and environmental benefits. Our challenge is to ensure that sustainability is recognised not just as an environmental consideration, but as an ethos that brings together economic efficiency and environmental protection while meeting social and corporate objectives across the whole organisation.

Climate change adaptation is how we need to adapt to operate within a changing climate and deal with the impacts of such change. Many of the Highways Agency's activities are either directly affected or influenced by the weather and climate. Many of the impacts will be adverse, but some may be positive.

Our response to the challenge of climate change must involve both mitigation (taking action to reduce greenhouse gas emissions) and adaptation (adapting and changing behaviour so that it is more appropriate to the expected future climate). This report is focused on adapting to climate change although we recognise these two areas are highly interdependent.

Global scientific consensus is that the world's climate is changing. [Stern Review](#) (2007)<sup>2</sup> highlights climate change as a serious and urgent issue and the need for action is widely acknowledged. Scientific evidence<sup>3</sup> indicates that the rapidly changing climate is predominantly a result of increases in greenhouse gases caused by human activities.

On what does climate change mean for the UK?

The UK's climate is already changing. Average annual temperatures have risen by about 1°C in central England since the 1970s. While annual average rainfall has changed little, there are signs of a trend towards drier summers and wetter winters with heavier rainfall events. Sea levels around the UK have risen by around 1mm per year during the 20th century. The seasons now arrive on average 11 days earlier than in the 1970s.

[\(How well prepared is the UK for climate change?\)](#)<sup>4</sup> Adaptation Sub-Committee of the Committee on Climate Change, September 2010)

The ten hottest years on record have occurred since 1995. The 12-month period ending in April 2007 was the warmest period on record with July 2006 the warmest since observations began. The UK is probably warmer now than it has been at any time in the

<sup>2</sup> [http://www.hm-treasury.gov.uk/sternreview\\_index.htm](http://www.hm-treasury.gov.uk/sternreview_index.htm)

<sup>3</sup> <http://www.ipcc.ch>

<sup>4</sup> <http://www.theccc.org.uk/reports/adaptation>

last thousand years. This trend within the UK is consistent with the wider picture of a general world-wide warming noted by the IPCC, whose [4th Assessment Report](#)<sup>5</sup> concludes that warming of the climate system is unequivocal.

Long term changes in climate have been observed at continental, regional, and ocean basin scales as well as in the UK, and include changes in temperature, patterns of rainfall, of winds, and extreme weather. The IPCC also concluded that man is very likely responsible for most of the warming observed since the mid 20<sup>th</sup> century.

#### On Climate Change

One of the Highways Agency's key responsibilities is to play its part in delivering the Government's carbon reduction strategy for transport. We are recognised as a leader in our approach to this challenge and are addressing the growing threat of climate change; in terms of how we need to adapt to the changes, and to reduce our own emissions.

[\(Highways Agency Business Plan 2010-11\)](#)<sup>6</sup>

The Highways Agency's Adaptation Framework was originally developed inline with UKCIP02. Incorporation of the more recent UKCIP09 is ongoing and updated annexes will be produced in due course. The Met Office was consulted to ensure that no significant anomalies between the UKCIP02 projections we applied to our risk analysis and the probabilistic outputs of UKCIP09.

UKCIP09 provides the latest projections on the future climate of the UK providing significant advances on the previously available scenarios in UKCIP02. UKCIP09 uses a cutting edge peer-reviewed methodology to give a measure of the uncertainty in the range of possible outcomes. The projected changes provided by UKCIP09 depend on the emissions scenario, the region of the UK and how far in the future is of interest. The Highways Agency is committed to revising the climate modelling projections used in the adaptation strategy using the latest science from the UK Climate Impacts Programme to determine risks, implications and inform selection of adaptation measures.

To ascertain more specifically how future changes in climate could affect the Highways Agency, lists of primary climatic variables and secondary climatic impacts have been established:

#### Primary climatic changes:

- Increase in average temperature
- Increase in maximum temperature
- Increase in winter rainfall
- Reduction in summer rainfall
- More extreme rainfall events
- Increased wind speed for worst gales
- Sea level rise

#### Secondary climatic change impacts:

- Longer growing season
- Reduction in soil moisture
- Change in groundwater level
- Flooding
- Reduction in fog days in winter
- Reduction of icy days in winter
- Frequency of extreme storm surges

Although not specifically covered in UKCIP09, change in soil moisture (secondary impact) has been included due to the significant implications it may have on Highways

<sup>5</sup> [http://www.ipcc.ch/publications\\_and\\_data/ar4/syr/en/contents.html](http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html)

<sup>6</sup> <http://www.highways.gov.uk/aboutus/26993.aspx>

Agency assets including foundations and embankments. The increase in fog-free and ice-free days in winter will generally be a positive impact for the Highways Agency since both are recognised poor driving conditions, seriously limiting visibility and an increased risk of skidding respectively, with consequential accident risk.

#### On Policy: Severe Weather Plan

It is the Highways Agency's policy to ensure, so far as is reasonably practicable, that safe passage along the highway is not endangered by snow or ice, and alert procedures and actions are taken in the case of floods, severe gales, fog and heat waves.

(Severe Weather Plan, AMM 127, July 2010)

Changes are likely to exceed current natural variability. In broad terms, climate models suggest that we should expect to see a continuation of the changes that have been observed in the UK, albeit at an increased rate. Consequently, services that are demonstrably sensitive to current weather events are likely to become increasingly vulnerable in the future. UKCP09 projections will provide the Highways Agency with the tools to undertake quantitative options analysis.

#### Case study: Winter Resilience Review

In October 2010 an independent review was published into the resilience of England's transport system to severe winter weather. The report recognised the Agency's previous successes.

Our research, which was praised by the review, has also put us in a better position. Following our experiences we've updated our guidance so that our suppliers use up to 30% less salt. Coupled with our pre-wet fleet of salt spreaders, which use around 25% less salt, we should be consuming a lot less resource this winter.

On 01 December 2010 the Secretary of State asked David Quarmby CBE to carry out an urgent audit of how well the highway authorities and transport operators in England, including the Highways Agency, had been coping with the unexpectedly early and severe spell of winter weather.

Despite the severe weather conditions in 2010, the vast majority of our network remained open. Our winter fleet and Service Providers work around the clock with continuous salt treatment and snow ploughing in progress. Where incidents occur, our traffic officers, service providers, and maintenance teams work with the police to re-open lanes as soon as it is safe to do so.



Within long term general climate trends, extreme and untypical weather events will occur. Increasing average temperatures do not preclude cold spells. Similarly dry summers are very likely to have high rainfall events and winter precipitation may be snow. Climate change is a risk issue; we need to understand the risks to the asset, our operations and our main stakeholder the road user – our customer - from a changing climate. Now and for the future, we need to take appropriate, measured and timely action to manage these risks.

## 2. Highways Agency approach

We have developed a climate change risk assessment methodology as part of our approach to adaptation. This will enable us to incorporate climate change considerations into our design standards and specifications, routine maintenance, operating procedures, and the development of contingency plans. This will ensure the Highways Agency continues to operate a robust network. This need was recognised in our first Sustainable Development Action Plan (2007-08) and led to the development of the [Highways Agency Climate Change Adaptation Strategy and Framework](#)<sup>7</sup> which is available to stakeholders for review on the intranet and internet.

### On Highways Agency Commitment:

The Highways Agency will assess the potential risks that climatic changes pose to the ongoing management, maintenance, improvement, and operation of the strategic road network. We will factor anticipated climatic changes into the delivery of our business and develop appropriate management and mitigation solutions to remove or reduce these risks.

(Highways Agency Climate Change Strategy, *September 2009*)

In support of the adaptation strategy, the adaptation framework has been developed. It has been designed specifically to meet our needs and to address key aims of the adaptation provisions of the Climate Change Act. The development of the adaptation framework has built upon detailed review of work by the Highways Agency, and organisations, including UKCIP (UK Climate Change Impacts Programme), IPCC (InterGovernmental Panel on Climate Change), and the Stern review. It has been guided by consultation with a stakeholder group comprising members from the Highways Agency, Defra, Met Office, and other government departments and interested groups.

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<sup>7</sup> <http://www.highways.gov.uk/aboutus/24180.aspx>

**Case study: A new Memorandum of Understanding (MoU) between the Environment Agency and the Highways Agency.**

Signed by Paul Leinster and Graham Dalton, Chief Executive of the Highways Agency in November 2009, the purpose of the refreshed MoU included:

- To minimise flood risk, ensure compliance with relevant legislation and reduce the environmental impact of the road network

**Key Benefits to External Customers**

- Reduced environmental impact on the existing network by promoting sustainable design and build
- New roads are planned and developed to minimise the impact on the environment
- A quicker and more efficient response to incidents that threaten the environment and safety of road users

**Key Benefits for Addressing Future Challenges**

- Adapting to climate change
- Implementation of the Water Framework Directive
- Joint initiatives on environmental crime
- Further developing the use of sustainability and sustainable drainage techniques



The purpose of the adaptation framework is to enable the Highways Agency to systematically develop and implement our responses to the challenges of climate change in support of the delivery of corporate objectives. The framework provides a platform for decision makers to examine their individual business areas, determine associated risks (and opportunities) and identify preferred options to address and manage them.

Given that the UK transport sector has taken a lead in responding to the emergent threat from climate change, there are a number of potential business opportunities arising. For the Highways Agency this is the export of intellectual property, and supporting consulting know-how, in solving the problems identified. The fact that we are one of the UK Overseeing Organisations setting design and maintenance standards for the trunk (strategic) road network is an opportunity for embedding adaptation without having to create anything new.

### **Case study: The Design Manual for Roads and Bridges (DMRB)**

The “Design Manual for Roads and Bridges” (DMRB) was introduced in 1992 in England and Wales, and subsequently in Scotland and Northern Ireland. It provides a comprehensive manual system which accommodates, within a set of loose-leaf volumes, current Standards, Advice Notes and other published documents relating to Trunk Road Works.

The documents in the DMRB have been prepared by the Overseeing Organisations specifically for Trunk Road Works throughout the UK, subject to any restrictions contained in individual documents. The DMRB sets a standard of good practice that has been developed principally for Trunk Roads. It may also be applicable in part to other roads with similar characteristics. Where it is used for local road schemes, it is for the local highway authority (local roads authority in Scotland and Northern Ireland) to decide on the extent to which the documents in the manual are appropriate.

DMRB houses the standards for road design and construction many of which include consideration of weather related aspects of temperature, precipitation and wind where we can embed adaptation.



We are seeking to consolidate our previous work on climate change adaptation and mitigation. We have applied our climate change adaptation framework to the high priority areas of our business and assigned management actions to those key climate related risks. The next step is ensuring all areas of our business have considered the possible risks of a changing climate.

#### **On the Adaptation Framework Objective**

To enable the Highways Agency to systematically develop and implement its responses to the challenges of climate change in support of the delivery of its corporate objectives.

*(Highways Agency Climate Change Adaptation Framework, September 2009)*

We will be using the latest scenarios from the UK Climate Projections to further inform our work on adaptation, as well as contribute to internal guidance to ensure that the changing climate is factored into our new advice, technical standards and specifications.

### **3. Summary of risks which affect the Highways Agency**

The Highways Agency has well developed arrangements in place that demonstrate climate change is a clear component of corporate risk appraisal including:

- Climate change adaptation is recognised by the Accounting Officer as a key Agency initiative and reported in the Business Plan. Commitment to the Climate Change Adaptation Strategy is set out in the Business Plan 2010-11.

- Adaptation to climate change is a key consideration of the Highways Agency Board as demonstrated by inclusion of this risk in the corporate risk register (alongside other business risks). The strategic impact of this risk is reported monthly and the Agency’s mitigation measures are reported including the extent to which they are effective. A traffic light RAG rating is used to assess/report effectiveness of mitigation.

This engagement and management at Board level needs to be maintained.

A specific objective of our adaptation framework was to ensure the alignment of the Framework with our corporate objectives. We plan to continue assessment of climate change risks and response.

Highways Agency high-level climate-related risks to corporate objectives

Risk	Examples
Reduced asset condition and safety	Assets deteriorate more quickly due to changes in average climatic conditions; assets are more badly damaged as a result of more extreme climatic events.
Reduced network availability and/or functionality	Need for restrictions on the network to maintain safety; increased need for roadworks.
Increased costs to maintain a safe, serviceable network	Construction/maintenance/repairs/renewal required more often; more extensive construction/maintenance/repairs/renewal required; new (more expensive) solutions required e.g. designs and materials/components/ construction costs.
Increased safety risk to road workers	Increased risk to construction and maintenance workers and Traffic Officers as a result of climatic change e.g. if need to work on the network more often; if required to work on the network during extreme climatic events or if climate change requires them to perform more ‘risky’ activities.
Increased programme and quality risks due to required changes in construction activities	More onerous design requirements; new technical solutions required with higher uncertainty, affecting project programmes and/or quality.
Current Highways Agency internal operational procedures not appropriate	Effects of climate change require new ways of working - changed or new business processes, new skills/competences.
Increased business management costs	Need for more staff; more frequent (expensive) incidents to pay for; need for more research into ways of coping with climate change.

Within the adaptation framework vulnerabilities are defined as Highways Agency activities that could be affected by climate change. Thus, whilst the Highways Agency’s assets are receptors of climatic events, it is, for example, the way in which these assets are designed, maintained and operated that is defined as vulnerabilities.

This definition of vulnerabilities has been used to reflect the fact that it is the way the Highways Agency works that needs to be adapted to meet the challenges of a changing climate. This emphasis on vulnerabilities also enables responsibilities for identifying, analysing and managing the risks associated with specific vulnerabilities to be assigned effectively to technical and operational staff who specialise in the relevant field of activity.

To stimulate the identification of vulnerabilities and enable them to be catalogued in a consistent manner, a vulnerability schedule has been developed which maps Highways Agency activities to associated climate change hazards and also to risks to the delivery of the Highways Agency's corporate objectives. Over eighty Highways Agency activities, or vulnerabilities, have initially been identified which may be affected by climate change.

The Highways Agency vulnerabilities schedule is at Annex A. These are categorised under:

- Defining and managing network strategy and planning
- Design and construction of new and replacement assets
- Maintenance and management of existing assets
- Managing network operations
- Internal business management

The vulnerability schedule provides a catalogue of risks to the Highways Agency. A preliminary appraisal of the risks associated with these vulnerabilities has been undertaken which found that over 60% of them are expected to be materially affected by current predicted levels of climate change within their relevant asset life or activity time horizon.

The objective of the risk appraisal process is to provide a means of 'scoring' the vulnerabilities to form hierarchies or rankings and to enable us to determine where to focus our efforts in adapting to climate change. Essentially, it provides a basis for future planning and prioritisation.

#### **4. Highways Agency actions proposed to address risk**

The risk appraisal has also enabled vulnerabilities to be prioritised for attention, based upon several criteria including their potential to disrupt the operation of the strategic road network. For example, it may be appropriate to prioritise action on the risks that have greatest potential effect on travellers; or those expected to materialise first; or those with greatest uncertainty for which further research would therefore be particularly beneficial; or some combination of these and other factors.

### **Case Study: National Flood Register**

The Highways Agency has already identified motorways and trunk roads vulnerable to flooding and has recruited emergency planning managers. The Agency launched the National Flood Register in 2009 and is undertaking schemes to provide better emergency access to motorways. The National Resilience Team acts as national coordination for the Highways Agency in managing the National Risk Register.

The Highways Agency responded to the Pitt Review by working through Local Resilience Forums to further consider motorway and trunk road vulnerability. As a result they are improving their Emergency Customer Welfare Strategy to provide delivery of basic emergency welfare to stranded motorists.



For this reason, the risk appraisal methodology uses multiple criteria. Separately and in combination, these criteria inform priorities for action. The primary criteria for risk appraisal are:

- Uncertainty - compound measure of current uncertainty in climate change predictions and the effects of climate change on the asset/activity.
- Rate of climate change – measure of the time horizon within which any currently predicted climate changes are likely to become material, relative to the expected life/time horizon of the asset or activity.
- Extent of disruption – measure taking account of the number of locations across the network where this asset or activity occurs and/or the number of users affected if an associated climate-related event occurs. Therefore, an activity could be important if it affects a high proportion of the network, or a small number of highly strategic points on the network.
- Severity of disruption – measure of the recovery time in the event of a climate-related event e.g. flood, or landslide. This is separate from ‘how bad’ the actual event is when it occurs e.g. how many running lanes you lose; it focuses on how easy/difficult it is to recover from the event i.e. how long it takes to get those running lanes back into use.

For each vulnerability a High/Medium/Low score is assigned against each of the four primary risk appraisal criteria. This is achieved using sub-indicators and reference tables. Scoring is undertaken based on expert opinion, and necessarily involves some judgement.

## 5. Uncertainties and assumptions

Uncertainties are explicitly recognised in the climate change models, future greenhouse gases emissions and how climate change will affect the performance of Highways Agency assets. Embedded within the risk assessment is an uncertainty criterion which evaluates both the confidence of climate change predictions and the climate change impact on the asset/activity. Risk appraisal scores for uncertainty are determined from a review of climate change trends information and from expert opinion of how well the effect of climate change on a particular vulnerability is understood. Two sub-indicators corresponding to the uncertainty levels in climate change predictions and in climate change effects are assigned a High/Medium/Low score and the overall uncertainty score is determined.

The time horizon for climate change effects to become material is determined using predicted climate change trends and considering the timescale over which such changes are expected to impact on the vulnerability. It reflects the time period within which it is expected that it will be necessary to do something differently, for any of the following reasons:

- climate change drives action sooner/more often than would be done currently e.g. something as simple as increased frequency of grass cutting;
- climate change results in damage to an existing asset e.g. because current (climate related) design criteria have been exceeded; and,
- climate change results in unacceptable frequency of network disruption e.g. because of flooding.

The asset life/activity time horizon sub-indicator reflects the duration of the consequences of decisions concerning the vulnerability. Thus for example, decisions about the design criteria for new structures typically have consequences that remain throughout the life of the asset, which may be up to 120 years. In contrast, decisions concerning the implementation of an operational management process can be more short-lived. Asset life/activity time horizon is assessed against two categories; short-term (defined as less than 30 years) and longer-term (defined as greater than 30 years).

For a short-term asset/activity, changes that become material further into the future are less of a priority for early attention, as the renewals cycle will enable adaptation measures to be implemented nearer the time that climate change effects actually become material. For long-term assets/activities, there may be no such intervening opportunities even for effects that do not become material until the mid-to-long term, thus activities associated with these types of assets are a higher priority for early attention.

### **Case Study: Highways Agency Severe Weather Plan**

The Highways Agency has a Severe Weather Plan in place with all its Service Providers. There are direct links to the Met office through the National Traffic Control centre at Quinton to anticipate severe weather and the potential of flooding. Regional Traffic Control Centres and the Traffic Officer Service together with the emergency services provide the capability to put in place plans to deal operationally with specific severe weather threats.

Service Providers provide the necessary expertise to examine and inspect particular parts of the Agency's infrastructure – bridges, pavements, drainage, earthworks and ancillary facilities and equipment. Risk and resilience planning is undertaken and communicated into wider Government initiatives; this is coupled with scenario planning to develop appropriate contingency measures.



In addition to the climate uncertainty, the Highways Agency's ability to deliver adaptation solutions will be dependant on available financial resources. The long time horizon to significant climate change affecting the highway asset makes current investment and future appraisal a challenging aspect of planning. Current and emerging network resilience measures (focusing on weather prediction, meteorological subsystems detection, communication, response and contingency planning) serve short-term needs. The relatively short-term life of the road pavement (surfacing) means predicted rising temperatures are not a significant concern at current resurfacing rates of 8-10 years. Nevertheless, the double benefit of greater durability and temperature tolerance prompted the alteration of the Highways Agency pavement specification in 2008. Similarly, the road drainage design standard was altered in 2006 responding to the threats of climate change and increased precipitation. The design life of a road drainage system is some 60 years, so an additional capacity of up to 20% was required by the revised standard and represents a cost effective action respecting both asset life and climate change prediction.

Arguably greater uncertainty exists over future transport and road user demand, particularly over the long term. Existing Department for Transport project appraisal seeks appraisals to account for costs and benefits over a 60 year period. Within this period there is a range of inputs into forecasting; GDP growth, fuel price trends, vehicle efficiency changes and other national trends generally assessed and reported at a national level. Road user behaviour is also expected to change and generate new challenges. Not enough is known about the possible impact of long term changes in weather on driver behaviour. It is possible that both hot and cold extremes will increase road traffic while driver responses to the changing situations may lead to increase in accidents and delays.

While there is a growing awareness of the need to adopt climate change mitigation behaviour, supported in the transport sector by actions such as 'Act on CO<sub>2</sub>' the public awareness of adaptation is perhaps limited. The Highways Agency's seasonal driving guides have been published for a number of years. 'Think Ahead, Move Ahead' travel

plan advice is in 2nd edition. The Agency is committed to ensuring there are regular revisions of the seasonal driving advice and use the climate scenarios to determine how driving behaviour might change in the future and what the Highways Agency will need to do to ensure continued safety on the network. Vehicles are, in this context, assumed to be relatively short-lived artefacts (5-10 years typically) and it is considered that they will be adapted by manufacturers.

### Case Study: Highways Agency Seasonal Driving Advice

The Highways Agency run summer and winter campaigns which, through media work and partnership marketing, encourage self-responsibility by urging drivers to plan ahead, service their vehicles regularly, and carry an emergency kit. We also promote a range of travel information services to enable road users to make informed choices on how they use our road network.

In winter the we are asking drivers to check road conditions and the weather forecast before setting out. If conditions are poor, and your journey is not essential, then think about delaying it until conditions improve. Road users who decide to travel are strongly advised to check road conditions and the weather forecast. Listen to travel bulletins on the radio and take a severe weather emergency kit.



In determining the *extent* of disruption it is important to take account of the spatial variation of the relevant climatic event. If the vulnerability is sensitive to an extreme event, the event may be relatively localised, as could be the case for extreme rainfall, or may be highly correlated over a large area, as may be the case for extreme temperatures. Thus, a risk event associated with extreme temperatures may well occur at several places on the network at the same time thereby increasing the extent of disruption.

The assumptions applied to scores for the extent of disruption are defined as:

	Criterion: Extent of network affected
High	>80% of network/users affected, or any specific highly strategic routes/locations
Medium	20-80% of network/users affected
Low	<20% of network/users affected

The *severity* of disruption is a measure of how long it takes to restore network functionality. It is not a measure of the duration of the event itself, as this is not under Highways Agency control. Responsive actions following extreme events can be particularly disruptive because their timing cannot be controlled.

In the cases of vulnerabilities that give rise to managed interventions, such as maintenance actions, the severity of disruption is a measure of how much disruption

would arise if current practices are retained. For managed interventions, the degree of disruption can typically be controlled to a degree that is not possible for responsive actions following extreme climatic events.

The assumptions applied to scores for the severity of disruption are defined as:

	Criterion: Severity of disruption
High	Disruption time > 1 week
Medium	Disruption time 1 day – 1 week
Low	Disruption time < 1 day

## 6. Barriers to adaptation and interdependencies

The purpose of the prioritisation of vulnerabilities is to inform timescales for action and provide priority areas for early focus in devising adaptation strategies. Typically in undertaking a risk appraisal it is possible to identify priority areas through considering a composite measure of extent and severity. This is not the case here. There are several reasons why a vulnerability could be a priority for action. Thus, rather than developing a single league table of vulnerabilities, a series of tables that reflect different reasons for action were established.

From the long list of vulnerabilities identified, we have pulled out those highly disruptive and time critical with high confidence. They have both high extent and high disruption duration. In addition, they are identified as time-critical with a confidence.

Category	Area	Aspect
Internal business management	Staff Costs	Staff numbers
Design and construction of new or replacement assets	Pavements	Materials specification and construction details
		Design of foundations
	Structures (including gantries)	Wind actions (loads) applied to superstructure
		Design for increased scour risk for foundations
		Design of bearings and expansion joints
	Drainage	Surface Water Drainage Systems
		Attenuation
Outfalls		
Maintenance and management of existing assets	Pavements	Skid resistance
		Integrity of materials
		Foundations
		Maintenance
	Structures (including gantries)	Wind actions (loads) applied to superstructure
		Management of increased scour risk for foundations
		Management and maintenance of bearings and expansion joints

Category	Area	Aspect
	Drainage	Surface Water Drainage Systems Outfalls
Managing network operation	Restricting network use	Flooding
Defining and managing network strategy, planning	Investment appraisal	Identifying best ways of investing resources/investment appraisal
	Strategic resilience	Critical geographic importance
	Network resilience	Impact from 3 <sup>rd</sup> parties
	Network resilience	Demand and operation (rail system fail)
	Budgeting (spending reviews)	Budgeting (spending reviews)

Even if a vulnerability receives a low risk-ranking based on the risk appraisal scoring, it may still be sensible to undertake early adaptation for reasons associated with the nature of the likely adaptation strategy, rather than due to the nature of the climate change risk itself. For example, if early action is straightforward and potentially highly cost-effective. In support of the prioritisation process, vulnerabilities are flagged in the risk appraisal process as early adaptation action advisable, if any of the following criteria are met:

- long lead-time needed to plan adaptation (e.g. to enable research or required changes to policy/standards to be introduced);
- significant planning/smoothing will be needed because many different locations on the network need to be worked on (e.g. lengthy national programme of works needed in order to adapt); or,
- adaptation is concerned with a long-life, expensive asset where it is suspected that there will be clear benefit derived from future-proofing new designs now (e.g. because marginal cost implications to future-proof now, but very expensive to address retrospectively).

The Engineering the Future group<sup>8</sup>, led by The Royal Academy of Engineering, the IET, ICE, IMechE and IChemE, was commissioned to carry out a study on the changes needed to make critical infrastructure robust against threats posed by climate change. This study looked at vulnerabilities in the transport, energy, water and communications infrastructure, to identify interdependencies between these elements of the UK's infrastructure, and identify strategies to increase the resilience of the entire infrastructure system.

The Highways Agency took part in both the workshop meeting in December 2009 directing this initiative to try to identify the key factors in estimating the damage to infrastructure under different climate models and a second phase of work on these problems, a workshop in July 2010, to examine how to improve the long-term adaptive capacity of the transport infrastructure against future climate change impacts. This

<sup>8</sup> [http://www.raeng.org.uk/societygov/public\\_affairs/thefuture.htm](http://www.raeng.org.uk/societygov/public_affairs/thefuture.htm)

looked explicitly from an engineering perspective – the challenges, barriers, opportunities and options to go forward – while recognising that there will be a wider context of regulation, policy, finance, etc.

Key barriers to implementation (internal, external, political, environmental, social, etc), are not identified in detail by the Highways Agency's own work, but our concerns are part of the Engineering the Future group study report. These barriers could push adaptation off track.

**Case Study: ENGINEERING, INFRASTRUCTURE & CLIMATE CHANGE ADAPTATION STUDY**

**From report of the Transport Sector workshop July 2010**

**Barriers**

“Uncertainty is perceived as the biggest single barrier to change. Currently the ‘risk’ of overinvestment in unnecessary resilience is seen as greater than the risk and consequences of failure. This situation is probably not helped by relatively short-term investment appraisals and high uncertainty in job security – and the rate of job turnover amongst Senior Executives.

“There are a large number of climate effects which are not properly understood or are not yet quantified at a sufficient level of certainty to support any specific changes in infrastructure, e.g. wind direction. While there are forecasts and models provided by the Environment Agency and the Meteorological Office, there are computational limits on processing data for climate forecasts – particularly given the processor hungry nature of the models that are currently being constructed.

“Availability of funding is as ever a challenge and the current and future economic circumstances in which infrastructure will exist are highly uncertain. From a regulatory perspective, it was suggested that standards need to be agile to remain relevant...

“Businesses within the sector tend to be organised in silos with climate change expertise often in one specific business area and not seen as central to operations.”

Clearly linked with uncertainty (need/justification) is the availability of funding especially with short term pressures to save money. This may affect the ability of the Highways Agency to deliver minimum whole life costs, a long standing critical driver of highways maintenance intervention in which we pride ourselves. Short term investment in long life infrastructure does not sit comfortably with long term climate change preparedness.

In addition, the Agency is committed to both climate change mitigation and adaptation, but a balance of resources may need to be struck in the future with tight fiscal constraints and concern for finite resources.

**Case Study: ENGINEERING, INFRASTRUCTURE & CLIMATE CHANGE ADAPTATION STUDY**

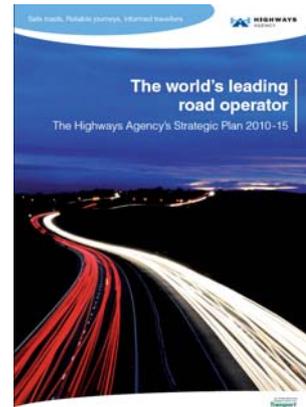
**From report of the Transport Sector workshop July 2010  
Interdependencies**

“The road network must be recognised and managed as a single network of assets. While it is not totally dependent on energy, in the sense that the network continues to function without signage, emergency signals etc the capacity of the system will be greatly reduced and traffic may be unable to enter or leave if traffic signals on local feeder roads lose power.

“There are significant and major interdependencies within the transport sector. Transport workers and managers must themselves travel to and from work, while the vehicles depend on the provision of energy – most commonly liquid fuel, delivery of which typically relies on road vehicles.

There are interdependencies between transport and ICT with management systems, control systems and communications systems all relying on provision of power and for electricity – to run transport infrastructure (e.g. electric trains) and management systems.”

Consequently, the Highways Agency’s Strategic Plan focus on reliability and accessibility; recognising that protecting the integrity of the network, and optimising its capacity, is still a fundamental responsibility for us.



The large number of high priority vulnerabilities classified as early action advisable will make management of them and monitoring of action plans difficult. With tight fiscal pressures, there is a mandate to prioritise early actions to ensure resources are focused into the highest area of need and where the Highways Agency will derive maximum benefits.

The primary impacts of climate change are through the increase in average and maximum temperatures, increased winter and decreased summer rainfall with an increase in extreme rainfall events, giving particular challenges in relation to drainage capacity and flooding (see Annex B). Flooding is expected to be an increasing problem and features frequently on the priority list above notably both directly against the drainage area and restricting network use. In addition to revised drainage standards, the Agency has initiated a better understanding of standing water on the road following high profile events of recent years.

The flooding events of autumn 2000, summer 2007 and November 2009 were a reminder of the risks posed by flooding, not only to residential and commercial properties, but also to strategic infrastructure. Following recommendations in the *Pitt Review*<sup>9</sup> the Highways Agency appointed consultants to report on the vulnerability of the network and to recommend measures to manage the risk. This report gives a

9

<http://webarchive.nationalarchives.gov.uk/20100807034701/http://archive.cabinetoffice.gov.uk/pittreview/hepittreview.html>

snapshot of the current risks and ways to manage them. The possible impact of climate change on flooding risks is well established, for example in *PPS 25 Development and Flood Risk*<sup>10</sup> and guidance on these climate change impacts was included in the latest revisions of highways drainage standards within the *Design Manual for Roads and Bridges* (DMRB)<sup>11</sup> (HD 33 and HD 45).

**Case Study: Highways Agency and Cumbria floods 2009**

The Highways Agency was part of the Infrastructure Recovery Group, which includes our service providers, Cumbria County Council (and its service providers), the emergency services, the Military, Utility Companies, and District Councils.

In November 2009 the Agency offered the following assistance to the Council:

- Geotechnical Engineers.
- Fluid Engineers (modelling floods and impact - potential solutions).
- Topographical Surveys.
- Project Managers.
- Vehicles/Plant.
- Lighting Units/Generators.
- Access to the Highways Agency supply chain.

The Council took up the offer of vehicles, plant machinery, and lighting units/generators, but did not need to take up the remainder of the assistance offered. The Agency provided the Council with an Under-Bridge Inspection Unit (a significantly large and specialised piece of machinery) – capable of giving access to the underside of bridges. This was sourced and delivered to-site, from Brighton, within 12 hours of the request and remained in place for a week.

Scour to structures from more intense rainfall became a reality for a local authority road bridge in November 2009. In August 2006, advice note BA 74/06 *Assessment of Scour at Highway Bridges* was published in the DMRB. BA 74/06 is weak on management strategies and a number of other weaknesses in the document have been identified that need to be addressed. As concerns over climate change continue to build, the Highways Agency is adopting its Climate Change Adaptation Framework and Strategy. In this context, a consistent Scour Management Strategy is considered necessary for implementation across the whole motorway and trunk road network.

The severe rainfall and flooding events in Cumbria in November 2009 that resulted in the loss of several bridges underline the need to make progress on this matter. So while increased scour risk features as a design and maintenance concern within our vulnerabilities, it has become a particular focus of activity to identify critical infrastructure at risk from flooding incidents under climate change scenarios. This reactive behaviour illustrates the reality of prioritising vulnerabilities.

<sup>10</sup> <http://www.communities.gov.uk/publications/planningandbuilding/pps25floodrisk>

<sup>11</sup> <http://www.standardsforhighways.co.uk/dmrb/index.htm>

### 7. Monitoring and evaluation

The Highways Agency’s Adaptation Framework explains the methodology used to identify and compare options to manage the risks associated with the Agency’s vulnerabilities. This methodology provides a tiered approach enabling the assessment of options to be kept as simple as is required for the preferred option to become clear. Guidance on the identification of preferred options is provided.

To date only limited application of our own method has taken place. Nevertheless, we know the process should generally be applied separately to each of the vulnerabilities identified, unless a common adaptation action can be used to address several vulnerabilities. In many cases, the selection of a preferred option will be readily apparent, but in other cases detailed analysis will be necessary and justified, particularly in support of significant investment decisions. For this reason the options analysis process incorporates the possibility of using increasingly refined methods of options assessment where the identification of the preferred option is clouded by uncertainty or risk.

In some cases the preferred option will be to undertake some further research or monitoring, after which it will be appropriate to re-assess options for adaptation utilising the findings of this work. Similarly, the adaptation action plan may identify the need for a periodic review of the adaptation option being pursued.

#### Case study: Mitigating the Effects of High Wind

When mitigating the effects of high wind it is fundamental that the potential for problems is identified as early as possible. This will typically be through the provision of weather forecasts and other information sources e.g. Met Office National Severe Weather Warning Service.

There are two bridges that cross the River Severn, the M4 between junctions 22 and 23, and the M48 between junctions 1 and 2. Both bridges allow traffic to travel from England to Wales. There are agreed protocols between the Highways Agency South West RCC (SWRCC), our Traffic Officer Service, Gwent Police, Avon and Somerset Police and our service provider. Wind speeds on the M4 are monitored by Gwent Police, and will instruct either Traffic Wales or the South West RCC when speed restrictions/closures are required. The wind speeds on the M48 are monitored by the SWRCC and will set speed restrictions/closures where required. VMS signage is used to support the speed restrictions/closures.



The identification of the preferred option is informed through determining the minimum whole-life-cost option taking account of the direct and indirect costs of adaptation and of the consequences of climate related incidents. The likelihood and severity of climate related incidents will be dependent on the adaptation option being considered. Thus an investment in adaptation actions will typically lead to a benefit through reducing the likelihood and severity of climate related incidents, and therefore reducing the

corresponding direct and indirect consequence costs. It is not, however, appropriate for whole-life-cost to be used as the sole indicator of the preferred option.

The sustainability of adaptation options also needs to be taken into account, as does the level of uncertainty and the potential risks associated with each adaptation option. Our options analysis is concerned with developing a more thorough understanding of the vulnerability itself, determining feasible options to manage the associated risks, estimating the costs, benefits and consequences of each of these feasible options, and carefully selecting a preferred sustainable option.

The process for undertaking options assessment comprises four stages. The process commences with the identification of feasible options, followed by the determination of their expected outcomes. Costs and benefits are then established and finally a preferred option is identified, if one is clear.

The identification of the preferred option requires judgement, balancing the relative importance of the aspects such as whole life cost, uncertainties, risk, sustainability, etc. Their importance will vary between areas of Highways Agency activity and operations, and advice from a range of specialists will often be required. Typically research for standards on designing and managing highway assets will include obtaining current guidelines and standards on assessment and management used by authorities in the UK and internationally.

In establishing this balance of relative importance, reference should be made to the way in which Agency investment decisions are made in the relevant field. Once the preferred option is identified, an adaptation action plan is developed. The purpose of an adaptation action plan is to translate the preferred option determined through the options analysis into a detailed plan of what is to be done, when and by whom. The adaptation action plan should be sufficiently comprehensive to ensure that the investment of resources is effectively planned and managed. Its level of detail will be commensurate with the level of investment and risk.

## **8. Next Steps**

The Highways Agency's Adaptation Framework has been designed to provide a coordinated approach to meet the challenges of climate change. It establishes clear responsibilities for developing and implementing adaptation action plans in specific areas of activity. Importantly, management of the Adaptation Framework also provides strategic oversight of progress and overarching management of residual risk. Because adaptation and the developing strategy and framework are being built into Highways Agency business processes, risk registers etc., climate change adaptation will be an on-going consideration. Future foreseeable actions are timetabled below.

The Highways Agency is occasionally referred to as a learning organisation and we need to review the uptake of the Adaptation Framework and the commitment to the Strategy.

## Highways Agency Interim Climate Change Risk Assessment

The overall management and of implementation of the Adaptation Framework will require:

Programme management responsibilities	Action	Timetable
Monitoring legislative and other policy developments	Defra's strategy statement on adapting to climate change	Defra issued - September 2010
Dissemination and communication	Highways Agency Adaptation Strategy and Framework published on Agency website	November 2009
	Technical, national and international speaking events	Commenced 2007-08 and ongoing
	Ensure regular revisions of the seasonal driving advice and use the climate scenarios to determine how driving behaviour might change in the future and what HA will need to do to ensure continued safety on their network	Review benefits - March 2012
Developing training materials for technical and operational specialists	Internal awareness of climate change and adaptation needs	Commenced 2007-08 and ongoing
	Application of UKCP09 (see below)	
Monitoring developments and updating climate trends information	Highways Agency Adaptation Strategy and Framework to reflect the UKCP09 probabilistic climate change forecasts	Publish update - March 2011
	Agency offers evidence that the production of the risk assessment and adaptation plan has led to a change in the organisation's management of climate risks	March 2012
	Show how climate change risks will be reviewed on a periodic basis and how changes to new climate change projection data will be handled	Outlined as a five year review
Maintaining the vulnerabilities schedule	Action plan(s) for managing the risks of a changing climate recording risk and action/intervention	Consideration of all priority risks - March 2011
Agreeing an annual programme of work for options analysis and the development of adaptation action plans	Mitigation actions are targeted including a responsible owner, timescale and success measures (see above)	
	Highways Agency commitment to both mitigation and adaptation, resources need to be balanced and within fiscal	Consideration of HMT advice within

Highways Agency Interim Climate Change Risk Assessment

Programme management responsibilities	Action	Timetable
	constraints: HMT Green Book Supplementary Guidance on 'Accounting for the effects of climate change'	DfT/Highways Agency appraisal and project control - Ongoing
	Incorporates a “smart” plan in the adaptation programme to show that risk management actions are targeted and deliverable	March 2012
Producing the Climate Change Adaptation Progress Review Report.	Highways Agency Climate Change Risk Assessment	September 2010



# Highways Agency Interim Climate Change Risk Assessment

				PRIMARY CLIMATIC CHANGES							SECONDARY IMPACTS OF CLIMATIC CHANGE						'TOP LEVEL' HIGHWAYS AGENCY RISKS								
ACTIVITY CATEGORY	AREA	ASPECT	ID	increase in mean temperature	increase in extreme temperature	increase in winter precipitation	decrease in summer precipitation	increase in extreme precipitation	reduction in snowfall	increase in wind speed for worst gales	Sea level rise	longer growing season	reduction in soil moisture	change in ground water level	flooding	reduction in fog days in winter	reduction in ty days in winter	frequency of extreme storm surges	Reduced asset condition and safety *1	Reduced network availability and/or functionality *2	Increased costs to maintain a safe, serviceable network *3	Increased safety risk to road workers *4	Increased programme and quality risks due to required changes in construction activities *5	Current Highways Agency internal operational procedures not appropriate *6	Increased business management costs *7
Design + construction of new + replacement assets	Structures (including gantries)	Earth pressures used in design affected by change in ground water level	DC08			✓	✓							✓							✓				
Design + construction of new + replacement assets	Structures (including gantries)	Foundation settlement affected by change in groundwater level	DC09			✓	✓							✓							✓		✓		
Design + construction of new + replacement assets	Structures (including gantries)	Design for increased scour risk for foundations	DC10					✓							✓						✓		✓		
Design + construction of new + replacement assets	Structures (including gantries)	Design of structure drainage	DC11					✓													✓				
Design + construction of new + replacement assets	Structures (including gantries)	Use of temperature sensitive components or materials in construction or rehabilitation (e.g. FRP strengthening)	DC12		✓																		✓		
Design + construction of new + replacement assets	Structures (including gantries)	Design of bearings and expansion joints	DC13		✓																✓				
Design + construction of new + replacement assets	Structures (including gantries)	Climatic constraints on construction activities	DC14		✓			✓		✓													✓		
Design + construction of new + replacement assets	Drainage	Surface Water Drainage Systems	DC15			✓		✓							✓										✓
Design + construction of new + replacement assets	Drainage	Cross-culverts	DC16			✓		✓							✓										✓
Design + construction of new + replacement assets	Drainage	Road edge drainage	DC17			✓	✓	✓											✓	✓	✓				
Design + construction of new + replacement assets	Drainage	Attenuation	DC18			✓		✓							✓					✓	✓				
Design + construction of new + replacement assets	Drainage	Outfalls	DC19					✓						✓	✓					✓	✓				
Design + construction of new + replacement assets	Geotechnics	Erosion	DC20			✓		✓				✓		✓							✓		✓		
Design + construction of new + replacement assets	Geotechnics	Stability of earthworks	DC21		✓	✓		✓																	
Design + construction of new + replacement assets	Geotechnics	Drainage ditches	DC22			✓		✓													✓		✓		
Design + construction of new + replacement assets	Geotechnics	earthworks stability and compaction	DC23		✓		✓					✓									✓		✓		
Design + construction of new + replacement assets	Geotechnics	Earthworks construction across existing landslip.	DC24			✓		✓						✓						✓	✓		✓		

**HIGHWAYS AGENCY CORPORATE OBJECTIVES:**  
 - Improve road safety  
 - Reduce congestion and improve reliability  
 - Provide better information  
 - Protect the environment  
 - Deliver value for money

Highways Agency risks resulting from identified climatic changes

# Highways Agency Interim Climate Change Risk Assessment

**HIGHWAYS AGENCY CORPORATE OBJECTIVES:**  
 - Improve road safety  
 - Reduce congestion and improve reliability  
 - Provide better information  
 - Protect the environment  
 - Deliver value for money

Highways Agency risks resulting from identified climatic changes

'TOP LEVEL' HIGHWAYS AGENCY RISKS

ACTIVITY CATEGORY	AREA	ASPECT	ID	PRIMARY CLIMATIC CHANGES							SECONDARY IMPACTS OF CLIMATIC CHANGE							'TOP LEVEL' HIGHWAYS AGENCY RISKS								
				increase in mean temperature	increase in extreme temperature	increase in winter precipitation	decrease in summer precipitation	increase in extreme precipitation	reduction in snow/fall	increase in wind speed for worst gales	Sea level rise	longer growing season	reduction in soil moisture	change in ground water level	flooding	reduction in fog days in winter	reduction in ty days in winter	frequency of extreme storm surges	Reduced asset condition and safety *1	Reduced network availability and/or functionality *2	Increased costs to maintain a safe, serviceable network *3	Increased safety risk to road workers *4	Increased programme and quality risks due to required changes in construction activities *5	Current Highways Agency internal operational procedures not appropriate *6	Increased business management costs *7	
Design + construction of new + replacement assets	Signs & signals	Stability	DC25					✓		✓								✓								✓
Design + construction of new + replacement assets	Technology	Wind loading	DC26							✓																✓
Design + construction of new + replacement assets	Road markings	Design/specification	DC27			✓		✓											✓							✓
Design + construction of new + replacement assets	Soft estate	capital investment landscape	DC28	✓				✓				✓	✓						✓			✓				
Design + construction of new + replacement assets	Soft estate	capital investment ecology	DC29	✓				✓				✓	✓						✓							
Design + construction of new + replacement assets	NMU facilities	shelter provision	DC30		✓	✓																✓				
Design + construction of new + replacement assets	NMU facilities	Underpass	DC31			✓		✓											✓			✓				
Design + construction of new + replacement assets	NMU facilities	Drainage design	DC32			✓		✓											✓							
Maintenance and management of existing assets	Pavements	Skid Resistance	MM01			✓	✓								✓				✓		✓					
Maintenance and management of existing assets	Pavements	Foundations	MM02			✓	✓						✓	✓					✓		✓					
Maintenance and management of existing assets	Pavements	Integrity of materials	MM03	✓	✓		✓						✓						✓		✓					
Maintenance and management of existing assets	Pavements	Maintenance	MM04	✓	✓														✓							
Maintenance and management of existing assets	Pavements	Resurfacing	MM05	✓	✓																	✓				
Maintenance and management of existing assets	Structures (including gantries)	Thermal actions (loads) applied to superstructure	MM06		✓														✓		✓					
Maintenance and management of existing assets	Structures (including gantries)	Wind actions (loads) applied to superstructure	MM07							✓										✓		✓				
Maintenance and management of existing assets	Structures (including gantries)	Increased thermal range giving rise to increased earth pressures for integral bridges	MM08	✓	✓														✓		✓					
Maintenance and management of existing assets	Structures (including gantries)	Earth pressures used in design affected by change in ground water level	MM09			✓	✓						✓						✓		✓					
Maintenance and management of existing assets	Structures (including gantries)	Foundation settlement affected by change in groundwater level	MM10			✓	✓						✓						✓		✓					







Transport Interdependencies relative to Telecoms, Water and Energy Infrastructure  
 (From ENGINEERING, INFRASTRUCTURE & CLIMATE CHANGE ADAPTATION STUDY  
 Report of the Transport Sector workshop July 2010)

	Telecoms				Water								Energy					
	landline		wireless		drinking		sewerage		surface		rivers		electricity		gas		oil	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Roads	H	M	L	L	L	L	M	M	H	H	H	H	M	M	L	M	L	M
Pedestrian routes	L	L	L	L	L	L	H	L	H	M	L	L	L	L	L	L	L	L
Cycling paths	L	L	L	L	L	L	H	L	H	M	L	L	L	L	L	L	L	L
Surface rail	L	L	L	L	L	L	L	L	H	M	H	M	H	H	L	M	L	M
U/G rail	H	M	M	L	L	L	M	L	M	M	M	M	H	H	L	M	L	M
Airport	H	M	H	M	M	M	H	L	M	M	H	M	H	H	L	M	H	H
Air ways	L	L	H	H	L	L	L	L	L	L	L	L	L	L	L	L	H	H
Terminals	M	M	M	M	H	M	H	L	M	M	M	M	H	M	L	M	L	M
Coastal infrastructure	H	M	H	M	M	M	M	M	M	L	L	L	H	L	L	L	L	L
Seaports	L	L	L	M	H	L	H	M	M	M	H	M	M	M	L	M	L	M
Inland waterways	L	L	L	M	L	L	L	L	H	M	H	M	L	M	L	M	L	M
Embankments	L	L	L	L	L	L	M	M	H	M	H	M	L	L	L	L	L	L
Tunnels	L	L	L	M	L	L	L	L	M	M	H	M	H	M	L	M	L	M
Bridges	L	L	L	L	L	L	L	L	L	L	H	M	L	M	L	M	L	M
Pipelines	H	L	H	L	L	L	L	L	M	M	L	M	H	M	L	M	L	M
Control systems	H	M	H	M	L	L	L	L	M	M	M	M	H	M	H	H	L	M
SatNav	M	M	H	H	L	L	L	L	L	L	L	L	H	L	L	L	L	L
Oil Distribution	M	M	H	L	L	L	L	L	H	M	L	L	H	M	L	L	L	L
Gas Distribution	M	M	H	L	L	L	L	L	H	M	L	L	H	M	L	L	L	L
Electric car recharge network	H	H	H	H	L	L	L	L	M	M	L	L	H	M	L	L	L	L
CO2 transport	M	M	M	M	L	L	L	L	H	M	L	L	H	M	L	L	L	L
Notes	<ul style="list-style-type: none"> <li>• If oil distribution networks are damaged transport is severely impacted but the infrastructure remains intact</li> <li>• There are interdependencies within interdependencies eg loss of gas supplies leads to a high impact on the electricity infrastructure</li> <li>• Surface transport will be more electricity dependent and so more vulnerable in future years than now</li> </ul>																	

Likely Infrastructure Damage and Probability of an impact are each scored as High Medium Low